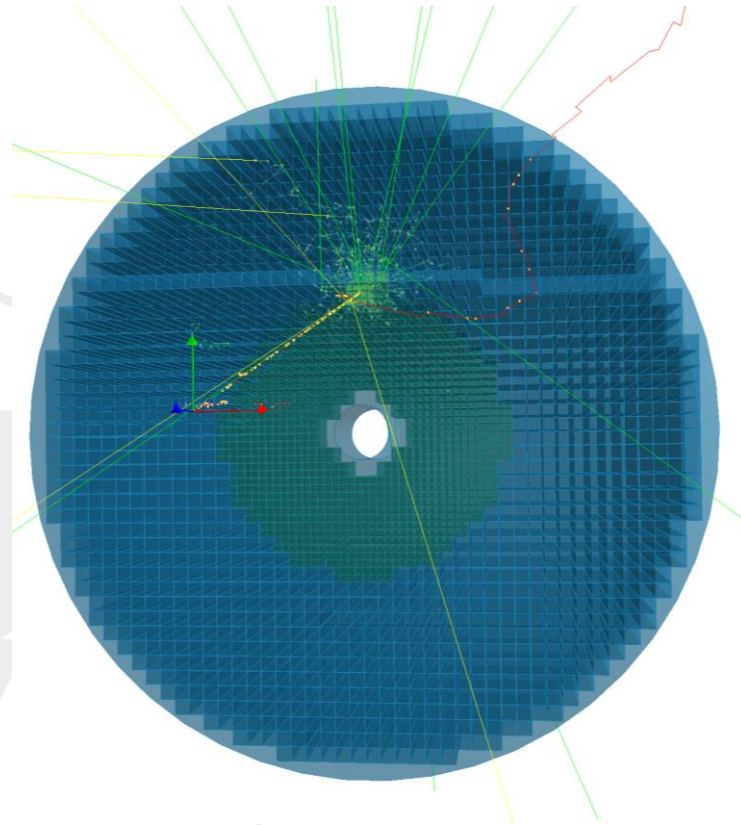


EIC Calorimetry

Dmitry Romanov (Jefferson Lab)

Hybrid Calorimeter Case

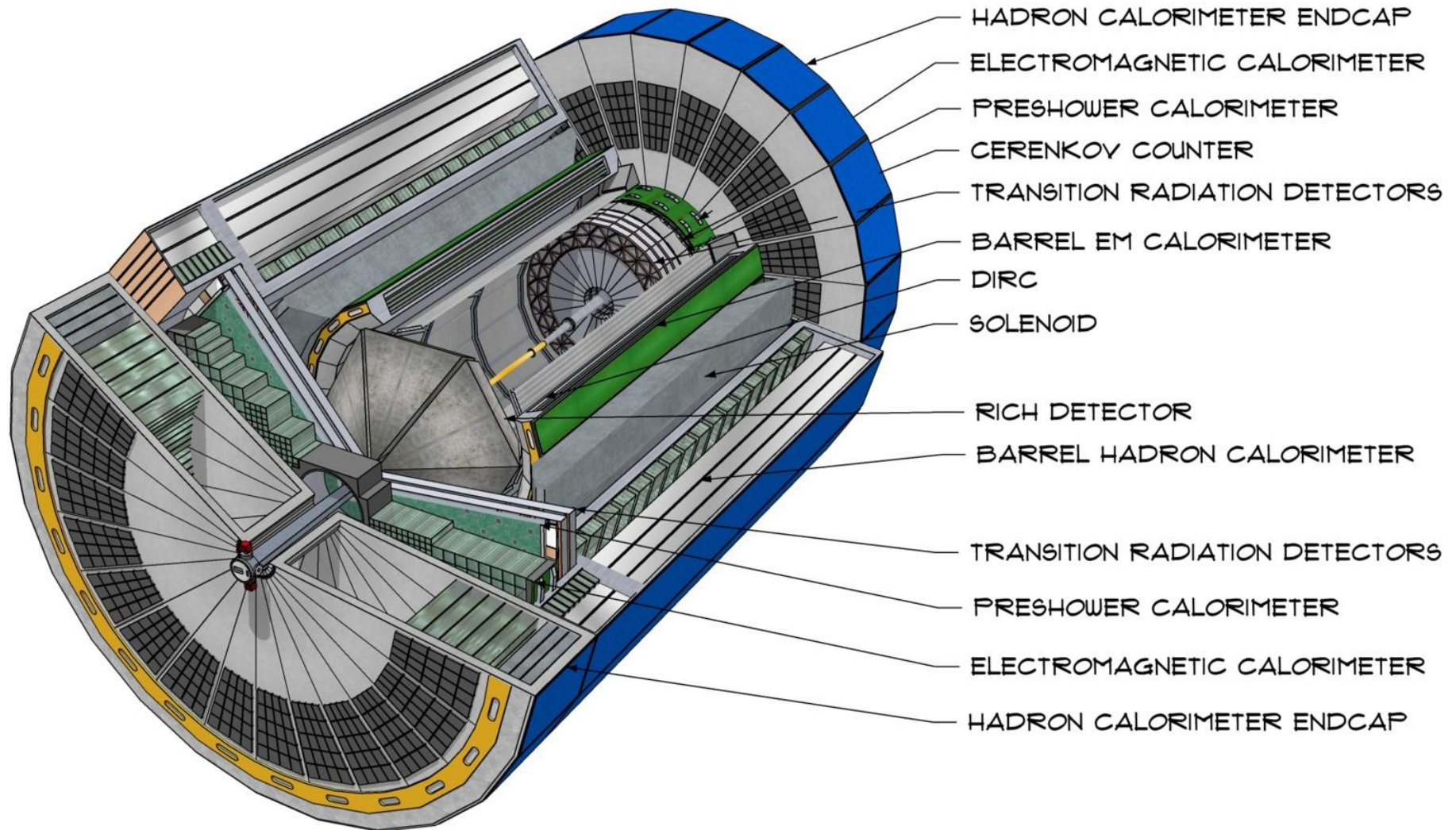


AI4EIC

September 8 2021

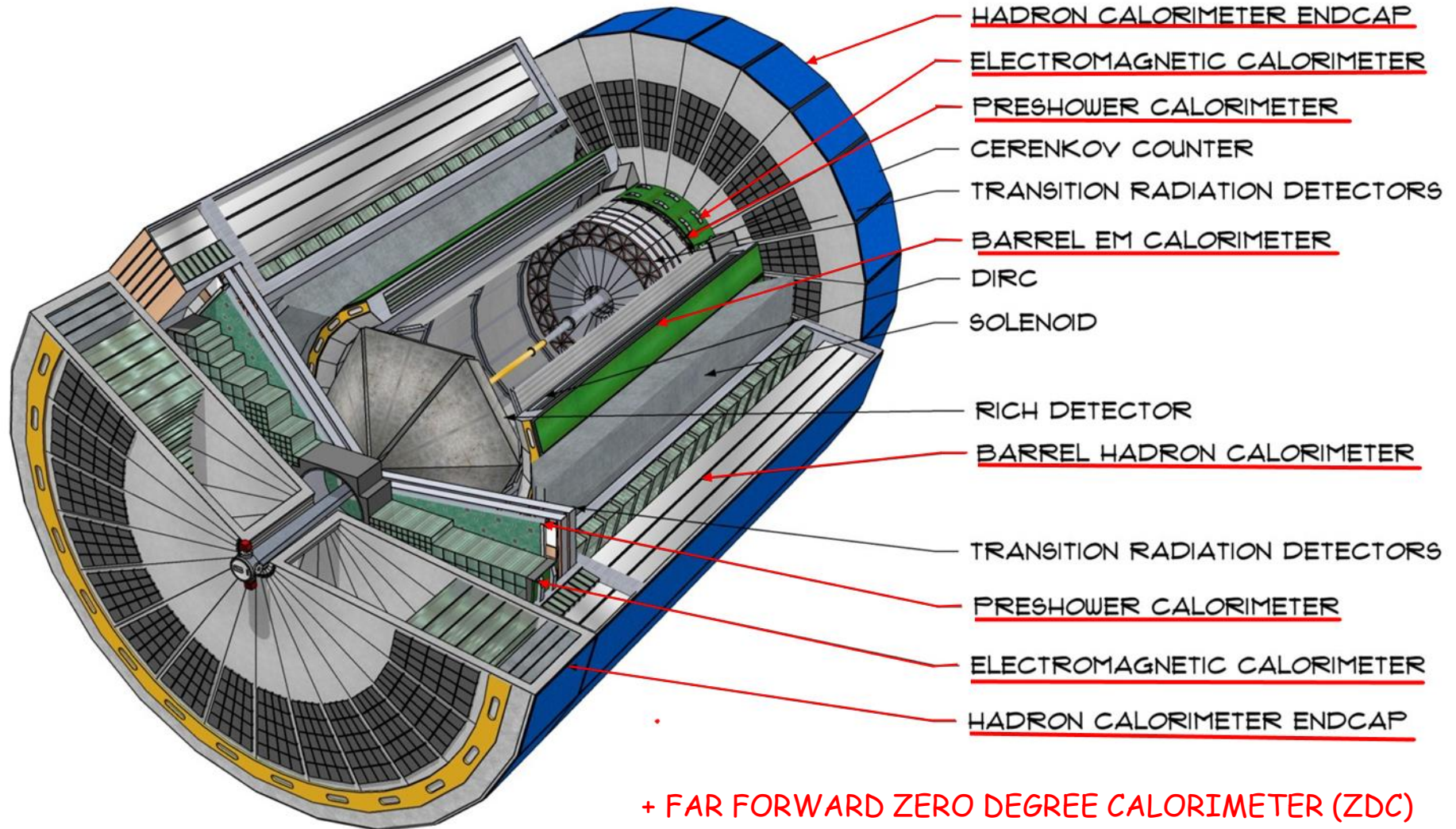
CAD Model of Generic EIC Detector

<https://arxiv.org/abs/2103.05419>



CAD Model of Generic EIC Detector

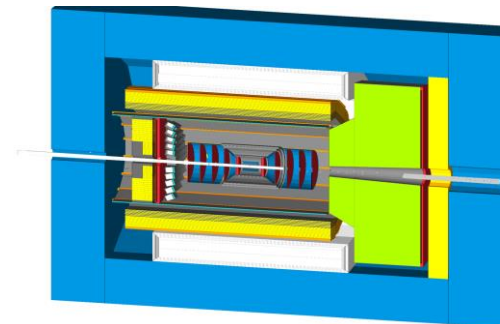
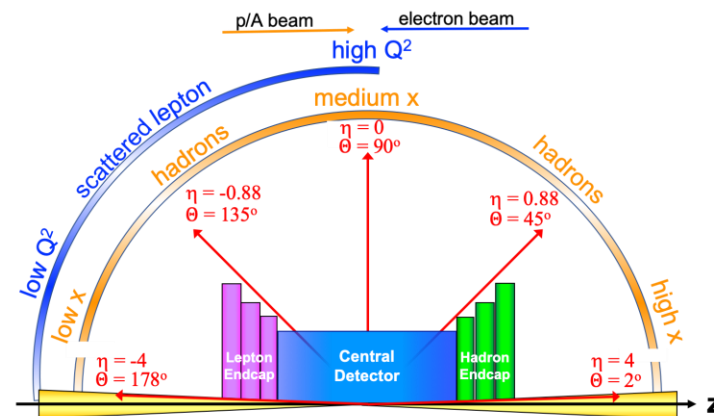
<https://arxiv.org/abs/2103.05419>



Calorimetry requirements and table

ECal	barrel	W powder/ScFi or Pb/Sc Shashlyk	SciGlass	W/Sc Shashlyk	
	forward	W powder/ScFi	SciGlass	PbGl	Pb/Sc Shashlyk or W/Sc Shashlyk
	backward, inner	PbWO ₄	SciGlass		
	backward, outer	SciGlass	PbWO ₄	PbGl	W powder/ScFi or W/Sc Shashlyk ^e
	very far forward	Si/W	W powder/ScFi	crystals ^f	SciGlass
HCal	barrel	Fe/Sc	RPC/DHCAL	Pb/Sc	
	forward	Fe/Sc	RPC/DHCAL	Pb/Sc	
	backward	Fe/Sc	RPC/DHCAL	Pb/Sc	
	very far forward	quartz fibers/ scintillators			

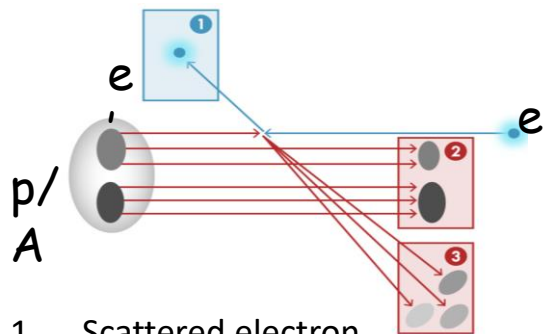
η	Nomenclature			Electrons and Photons			HCal	
				Min E	Resolution σ_E/E	PID	Min E	Resolution σ_E/E
-6.9 — -5.8	\downarrow p/A	Auxiliary Detectors	low- Q^2 tagger					
...								
-4.5 — -4.0			Instrumentation to separate charged particles from γ					
-4.0 — -3.5								$\sim 50\%/\sqrt{E} + 6\%$
-3.5 — -3.0	Central Detector	Backwards Detectors			$2\%/\sqrt{E} + (1-3)\%$			
-3.0 — -2.5								$\sim 45\%/\sqrt{E} + 6\%$
-2.5 — -2.0								
-2.0 — -1.5					$7\%/\sqrt{E} + (1-3)\%$			
-1.5 — -1.0						π suppression up to $1:10^4$		
-1.0 — -0.5								
-0.5 — 0.0								
0.0 — 0.5			Barrel	50 MeV			~ 500 MeV	$\sim 85\%/\sqrt{E} + 7\%$
0.5 — 1.0								
1.0 — 1.5					$(10-12)\%/\sqrt{E} + (1-3)\%$			
1.5 — 2.0								
2.0 — 2.5	Forward Detectors							
2.5 — 3.0								
3.0 — 3.5								
3.5 — 4.0								
4.0 — 4.5								
...								
> 6.2								
\uparrow e	Auxiliary Detectors	Instrumentation to separate charged particles from γ						
			Proton Spectrometer					



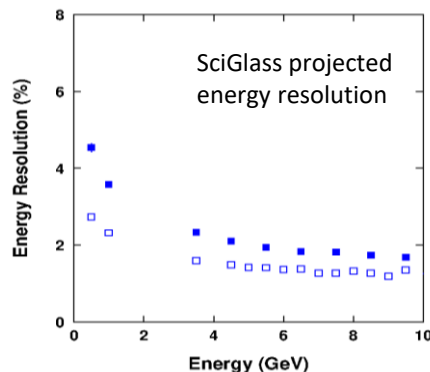
Lepton Endcap EM Calorimeter

Electron Detection - Goal

Scattered electron detection in the Lepton Endcap covering pseudorapidity -3.5 to -1 with



1. Scattered electron
2. Particle associated with initial Ion
3. Particle associated with struck quark



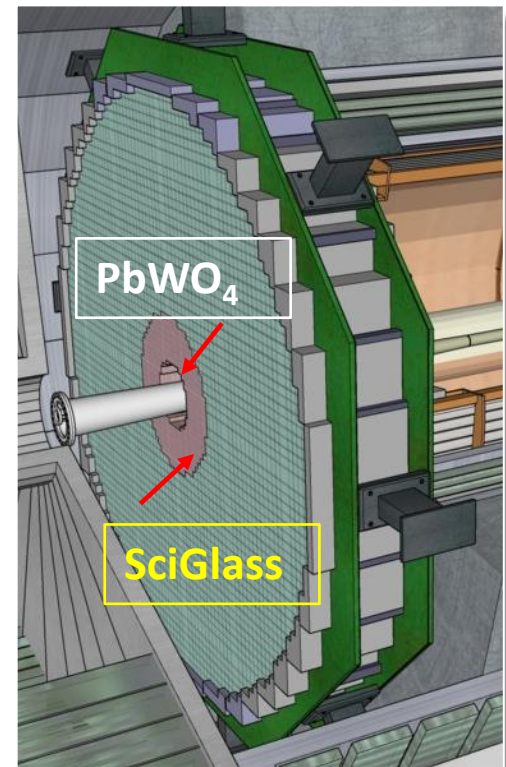
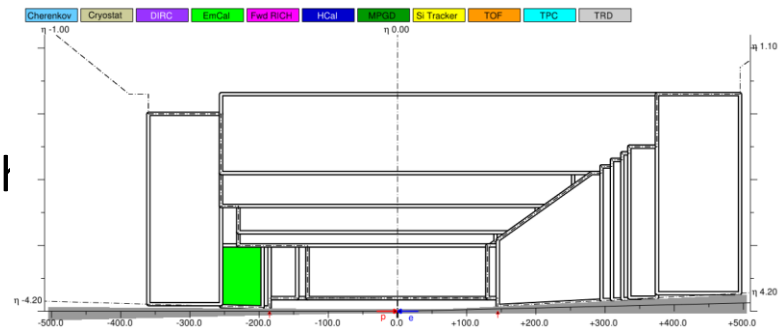
REFERENCE

PbWO₄ crystals (inner)

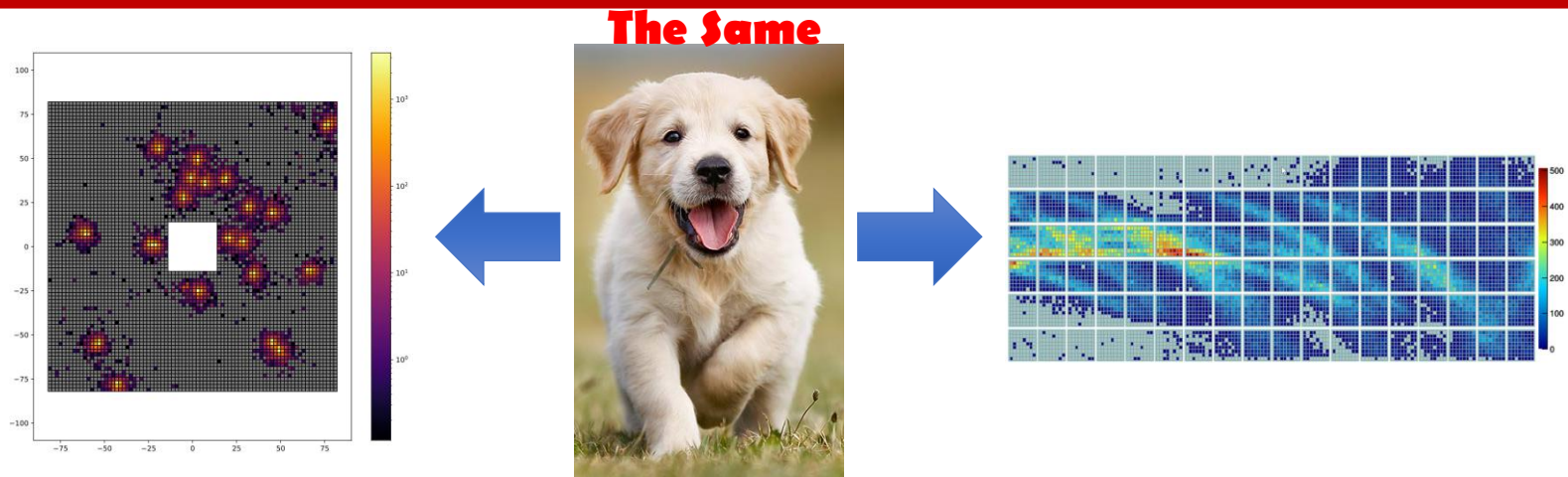
- compact, radiation hard, luminescence yield to achieve high energy resolution, including the lowest photon energies
- Sensor: SiPMs (TBC)

SciGlass (outer)

- EIC eRD1
- radiation hard, luminescence yield similar or better than crystals depending on longitudinal length
- Sensor: SiPMs (TBC)



AI for Hybrid EMCaI



AI DRIVEN CALORIMETER?

- AI driven optimization
- Reconstruction (special cases)
- Denoising
- Clustering
- Realtime FPGA processing
- Calibration
- Etc.

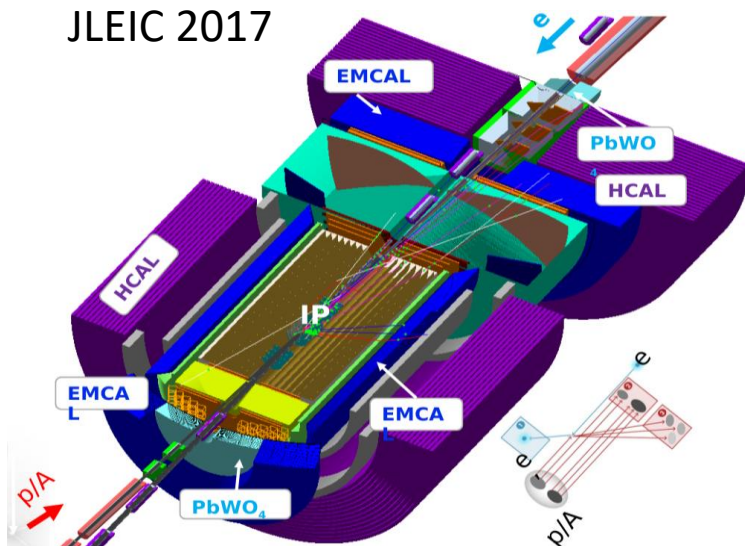
Hybrid EMCaI:

- Pixelated detector
- With pure 2d data representation
- Well studied parameters
- Existing robust reconstruction
- Yet still having many places of AI application

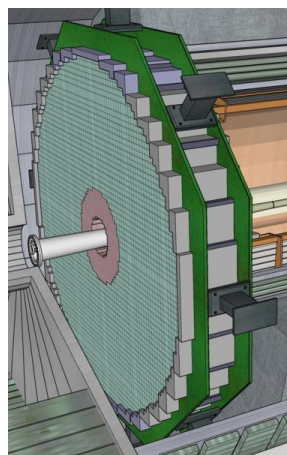
The project/s are in progress, the results are preliminary or in process

HyCal hybrid calorimeter

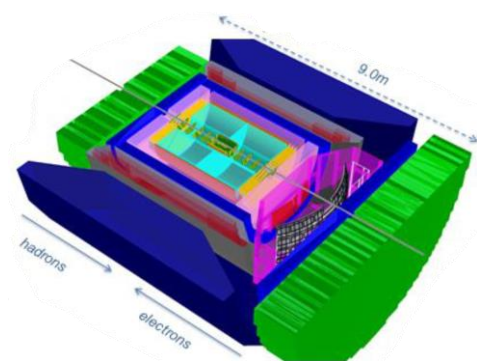
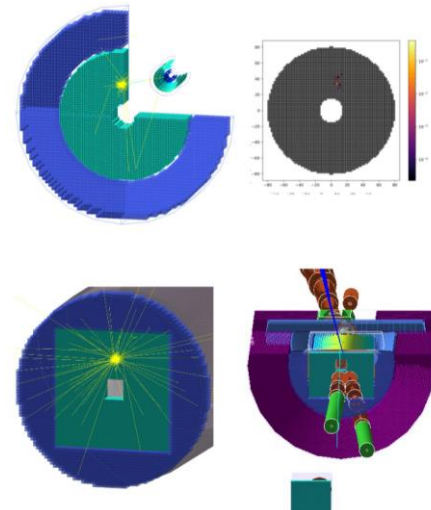
JLEIC 2017



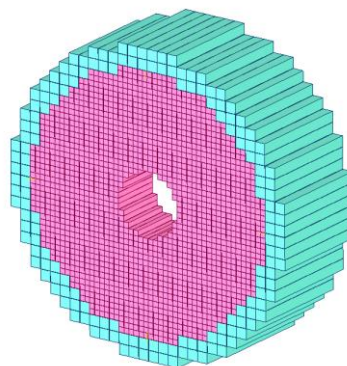
Generic model 2020



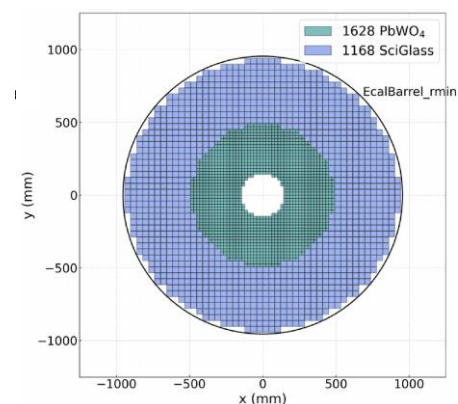
YP G4E 2019-2020



BEAST 2019



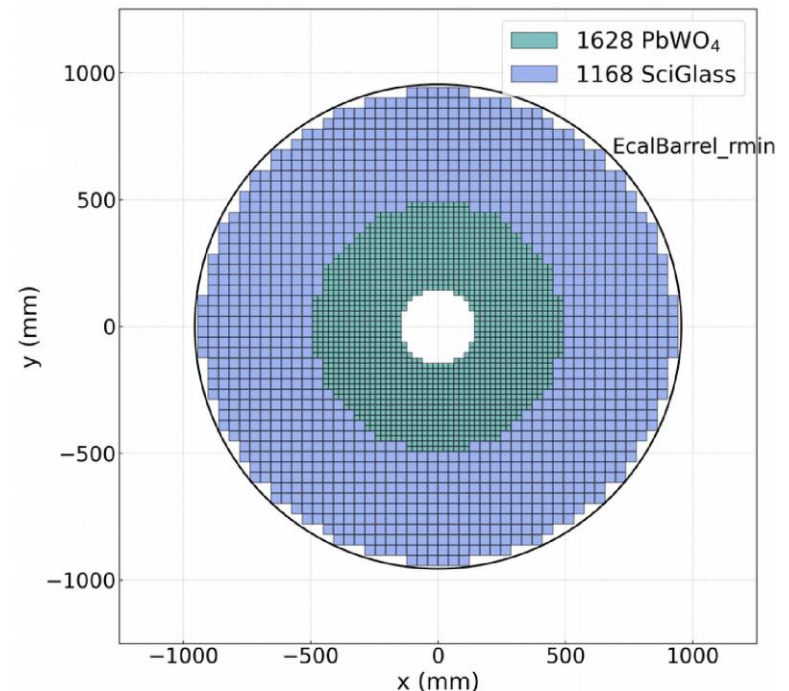
ECCHE 2021



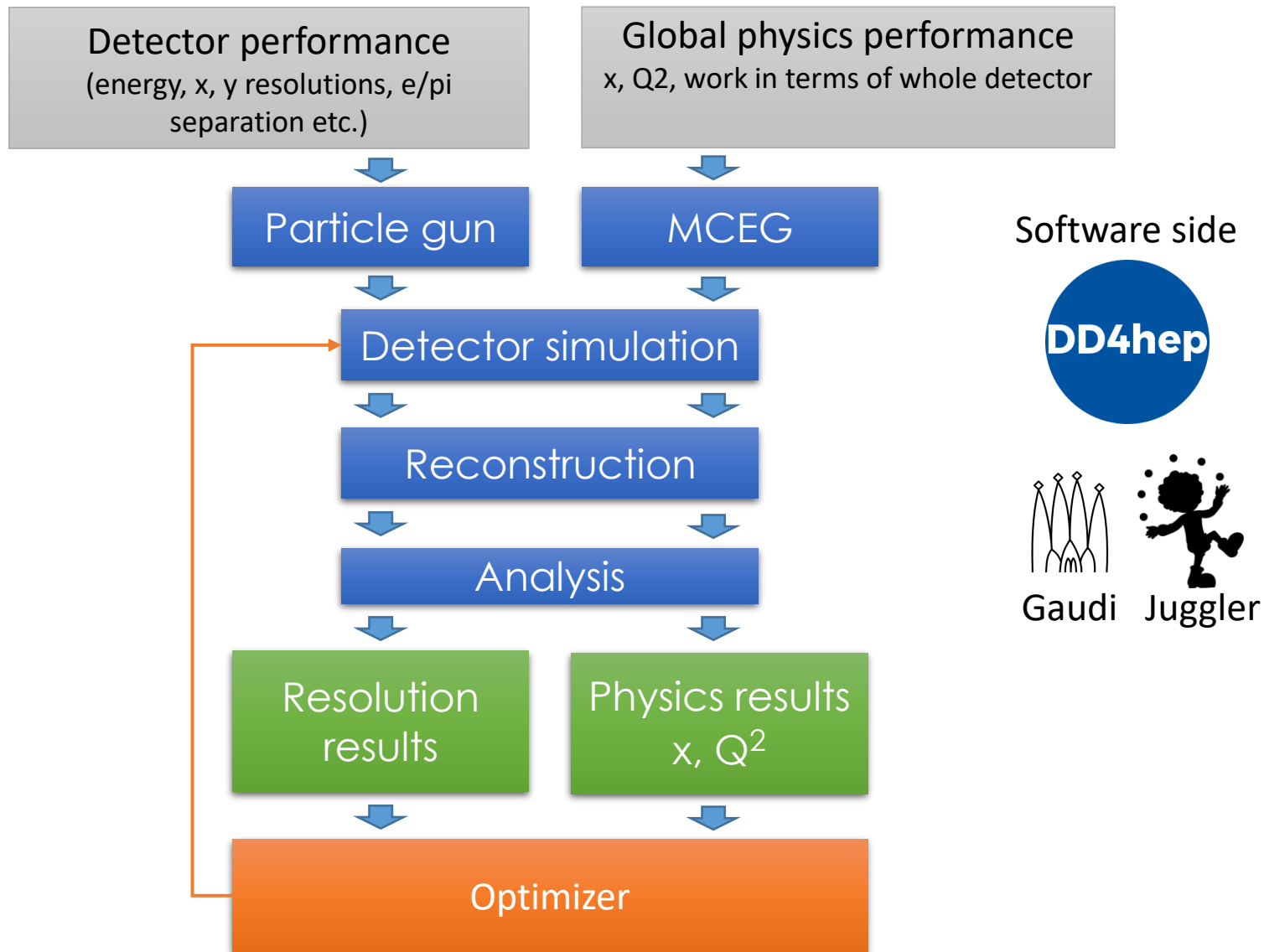
ATHENA 2021

AI Driven optimization

- ▶ Approach based on Cristiano Fanelli - Artificial Intelligence for the EIC Calorimeter Design
 - ▶ AI-optimized detector design for the future Electron-Ion Collider: the dual-radiator RICH case
- ▶ Points for Optimization:
 - ▶ Position
 - ▶ Geometries (Internal/External)
 - ▶ Crystal to Glass ratio
 - ▶ Materials
 - ▶ **Cost** (tricky)
- ▶ What is needed:
 - ▶ Resolution plots
 - ▶ Validation plots
 - ▶ X and Q^2 graphs
- ▶ Will use an unsupervised clustering algorithms
 - ▶ From Cristiano Fanelli (used in Hall B)
 - ▶ From Ilya Larin (used for HyCal, and FERMI Lab)
- ▶ Will use AI for transition region analysis

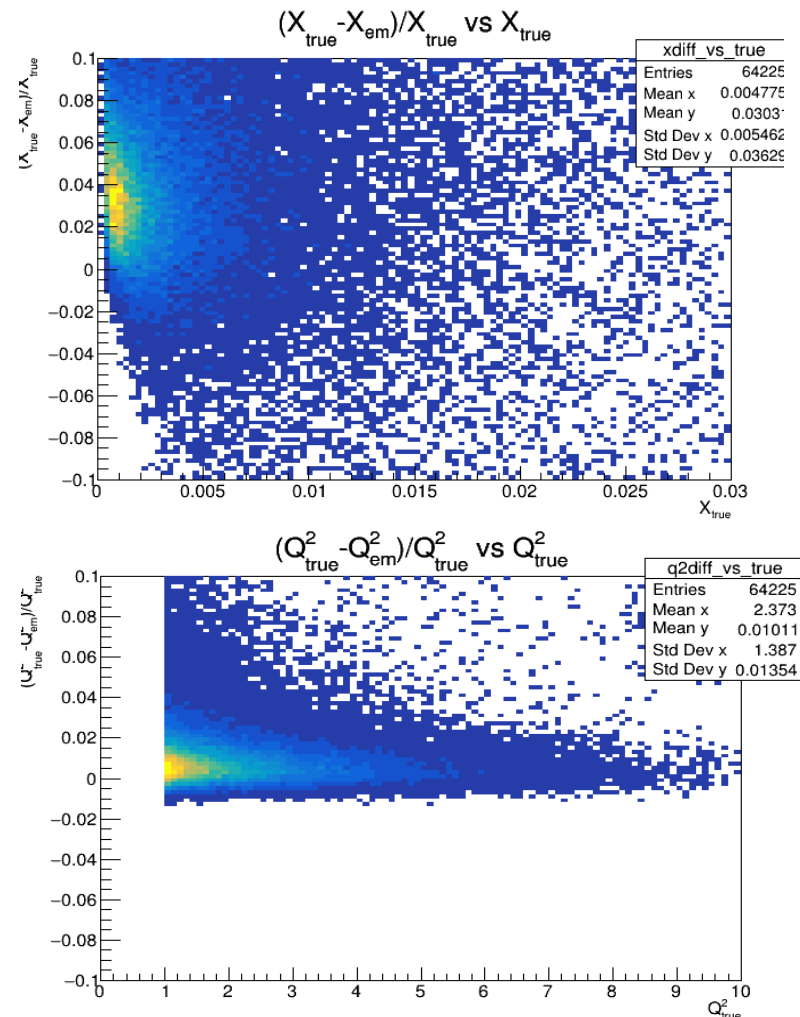
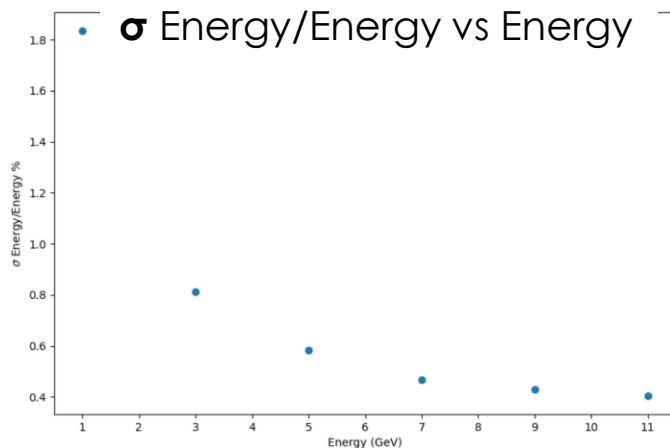


Optimization pipeline and software



Optimization pipeline details

- ▶ Events generation:
 - ▶ Particle gun
 - ▶ Event generators: Pythia8, BeAGLE
- ▶ Detector simulation – G4E / DD4Hep:
- ▶ Reconstruction – eJana (JANA2)/ Gaudi +Juggler
- ▶ Analysis + plots – python + jupyter
- ▶ **Established reconstruction pipeline** Cristiano



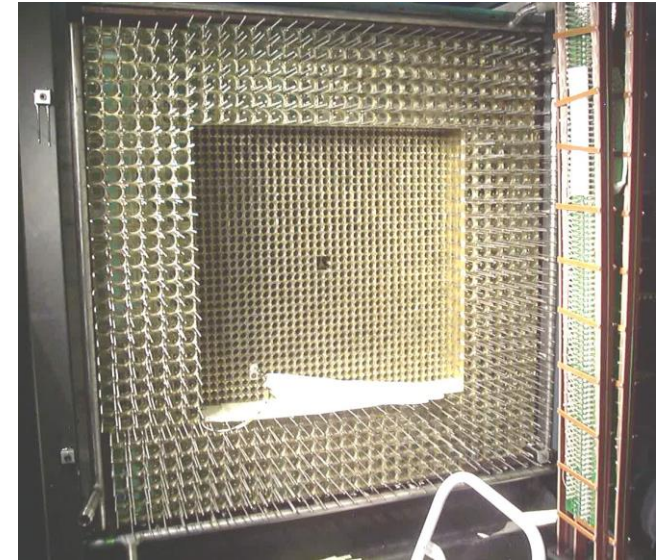
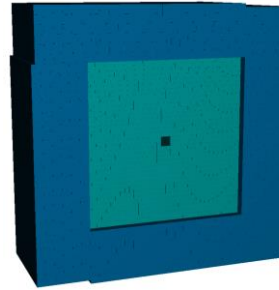
Can optimization benefit from ML reconstruction?

A. Boldyrev *et al* 2021 *J. Phys.: Conf. Ser.* **1740** 012047

Event reconstruction. Primex HyCal

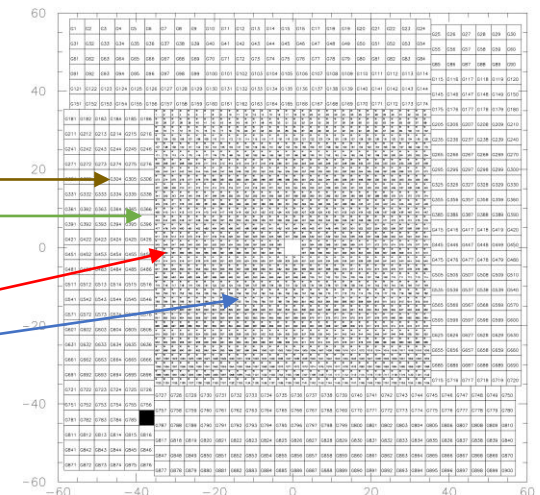
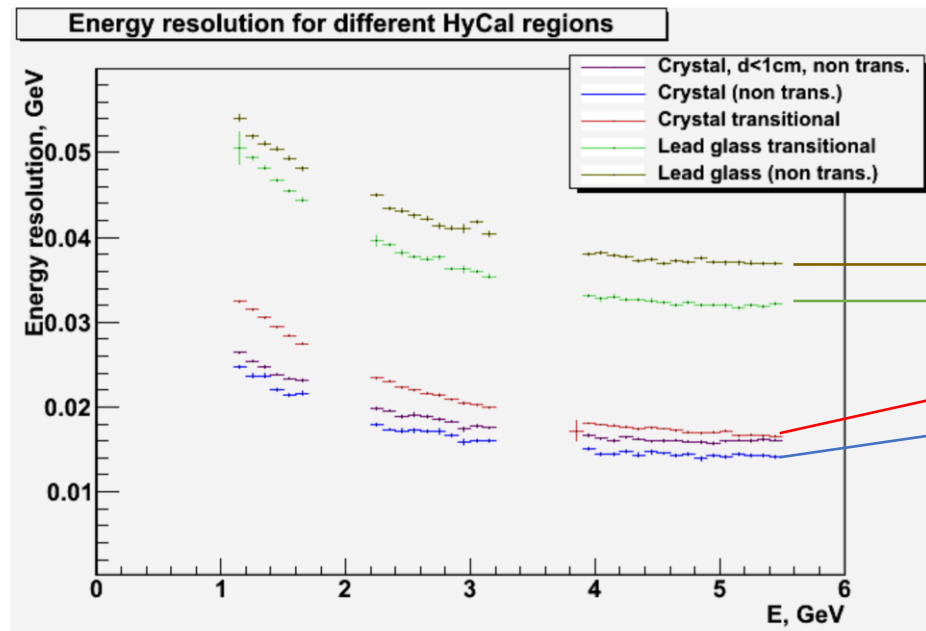
Hybrid calorimeter:

- PbWO₄ crystals inner
- Lead glass outer



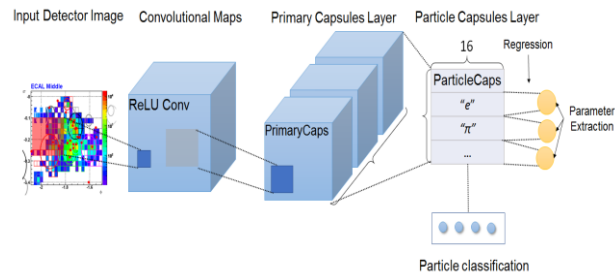
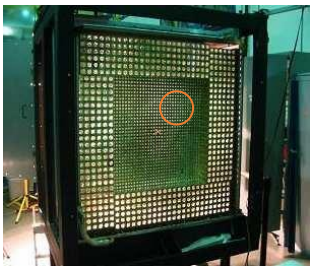
Relevant in terms of EIC as:

- The same kind of crystals
- Well known problems of the transition area
- Real data

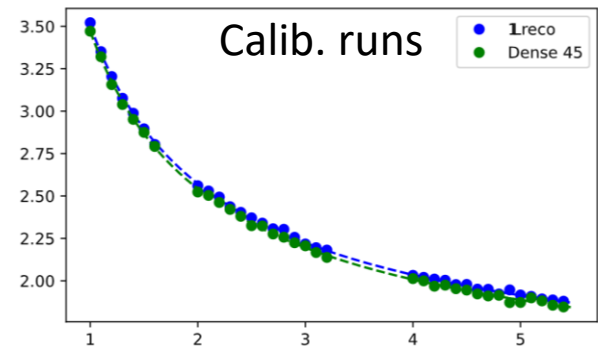
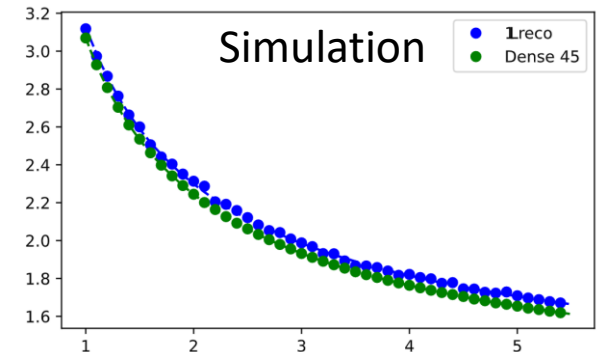


Applying different DNN to E, x, y parameters extraction

- Fast sim, geant3 (yes), real data sets
- Clean events (no pileup, no edge hits, etc)
- reco Island clustering + profile matching
- Applied different DNN architectures:
 - Dense (worked the best),
 - Conv (including VGG16, etc.)
 - ResNet,
 - ...,
 - Capsules!(didn't work)
- Tested transfer to real data (works!)



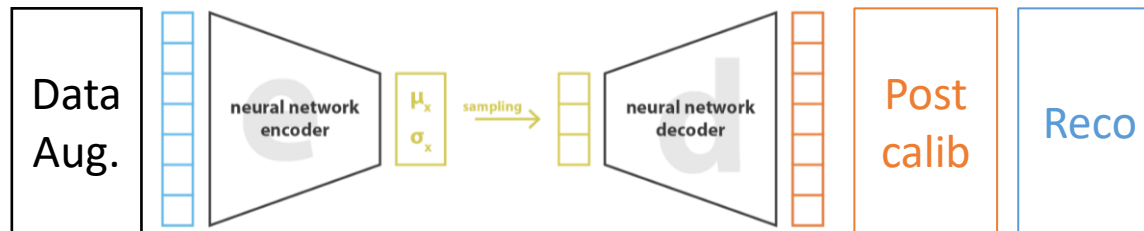
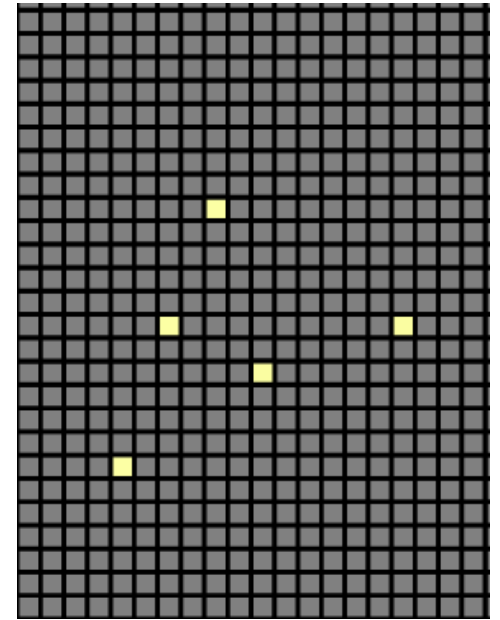
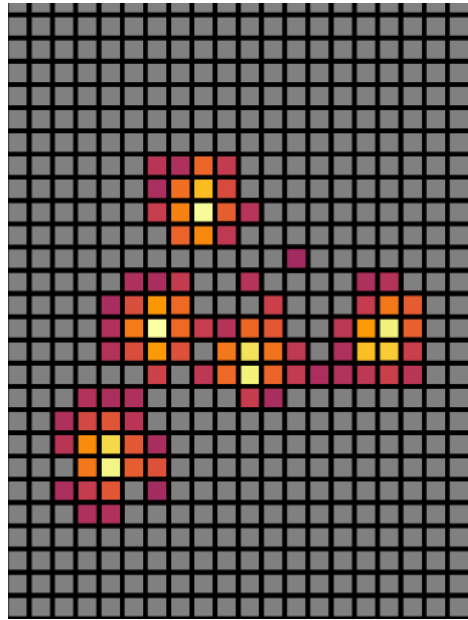
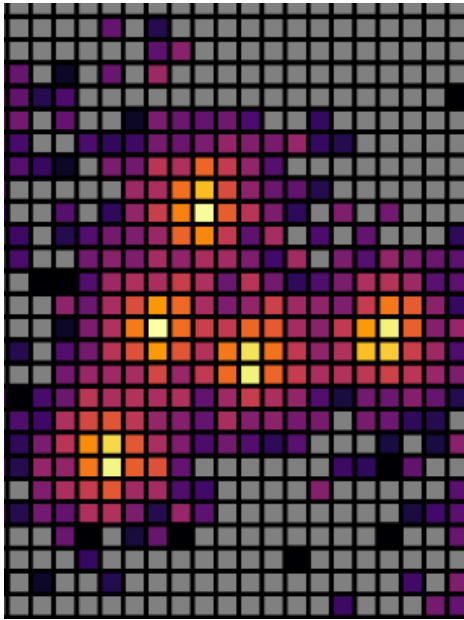
Example of application of Capsule networks



Noise reduction -> Better clustering

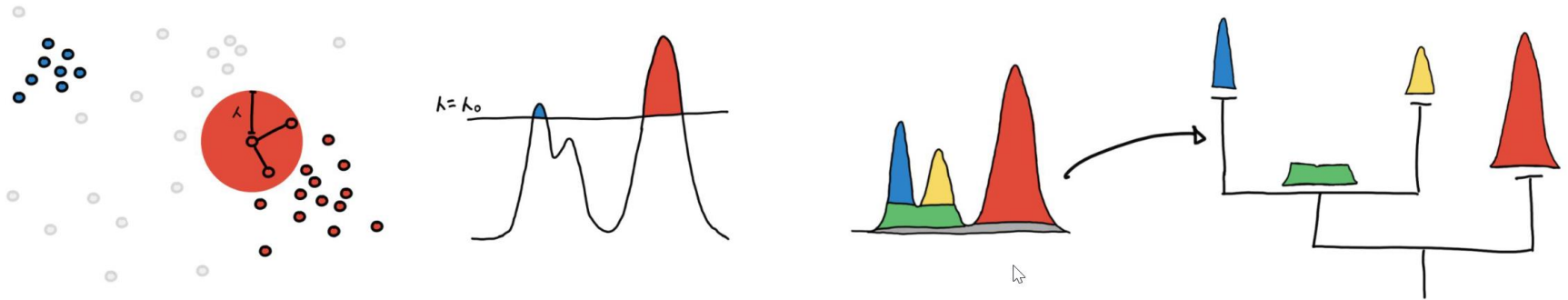
Can we apply noise reduction to drastically improve reconstruction performance?

- Apply VA to improve merged cluster reco
- Works amazing in some cases
- Worsen things in others
- Require future work and tuning



Unsupervised clustering

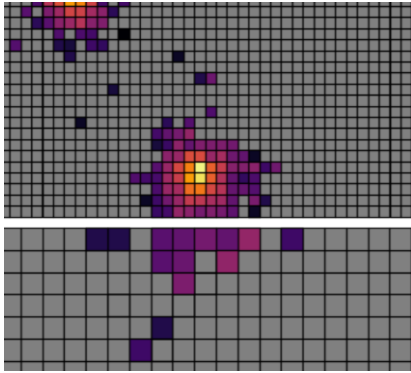
- Density-based methods:
DBSCAN , HDBSCAN, Clustering by Fast Search and Find Density Peak (CFSFDP), CLUE (parallelizable CFSFDP inspired), EWSCAN (DBSCAN inspired with Edge Weights)



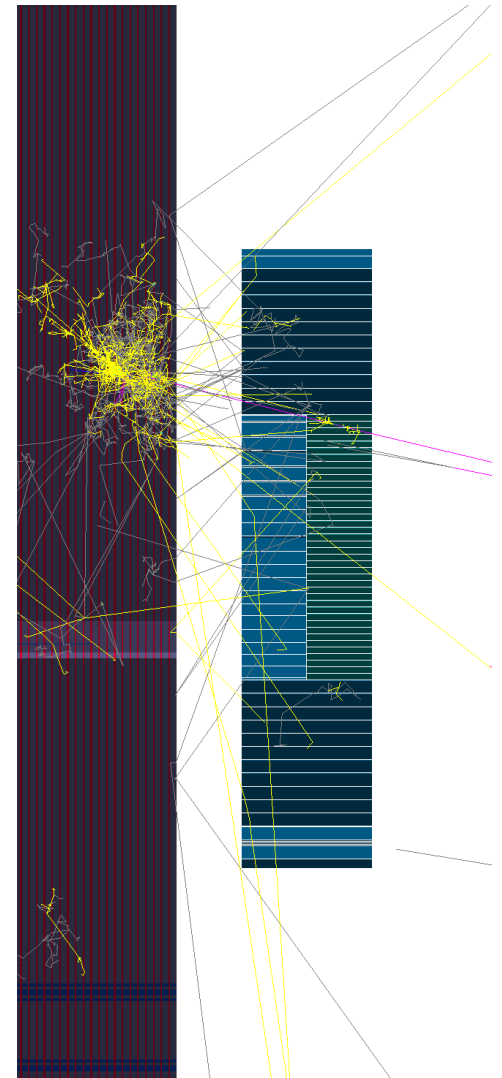
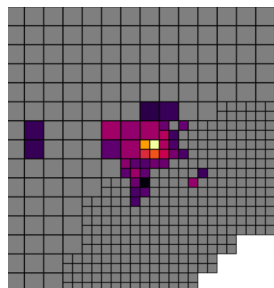
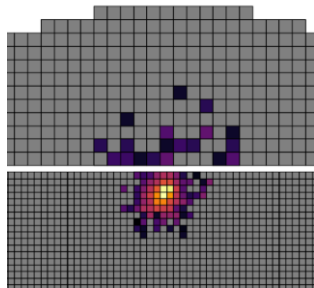
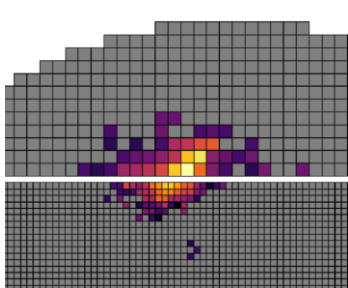
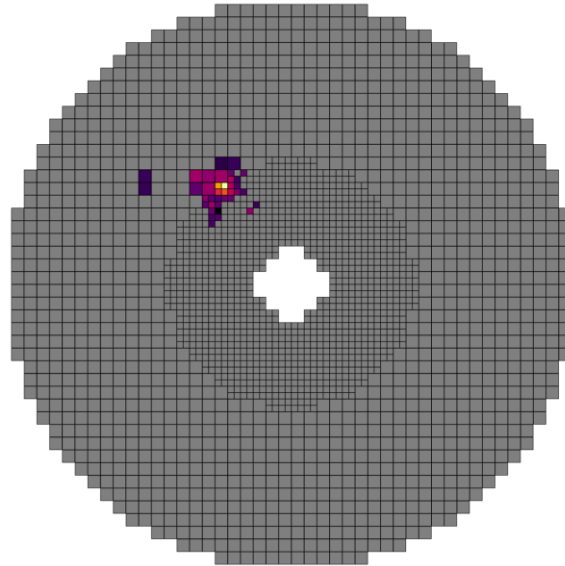
- Hierarchical clustering is an unsupervised ML technique to provide a hierarchy of clusters.
- It is based on estimate of density of points in a multi-dimensional space encoding detector information at the hit level (e.g., position, time, energy...).
- Hierarchy is defined through measurements of persistence and mutual reachability of points.

Transition region reconstruction

Crystal

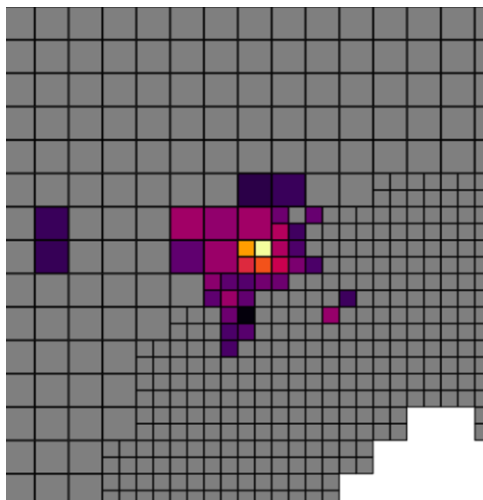


Glass



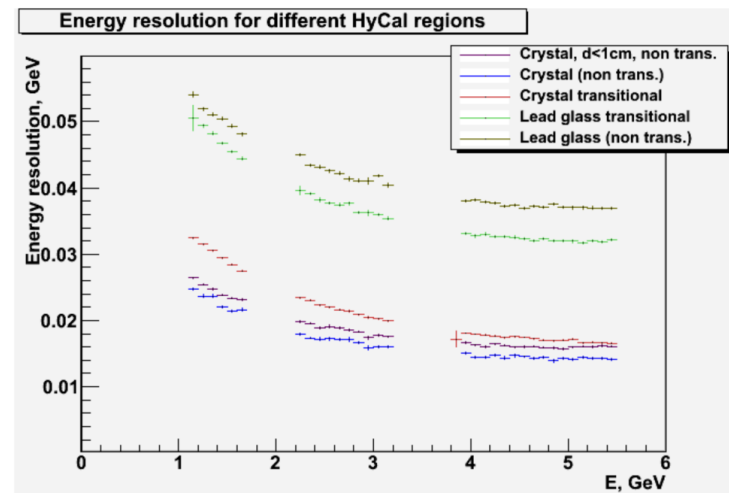
Transition area reconstruction (classic method)

- Reconstruct glass area alone
- Reconstruct crystal part alone
- Find matching clusters close together on glass/crystal
- Go over hypothesis applying synthetic χ^2 test to:
- Answer if those are from one, two, three... particles
- Try to apply cluster separation/reconstruction



		987	988	989	990	991	992	993	994
665	G666	W	W	W	W	W	W	W	W
		1021	1022	1023	1024	1025	1026	1027	1028
		W	W	W	W	W	W	W	W
		1055	1056	1057	1058	1059	1060	1061	1062
695	G696	W	W	W	W	W	W	W	W
		1089	1090	1091	1092	1093	1094	1095	1096
		W	W	W	W	W	W	W	W
725	G726	1123	1124	1125	1126	1127	1128	1129	1130
		G727	G728	G729	G730				
755	G756								

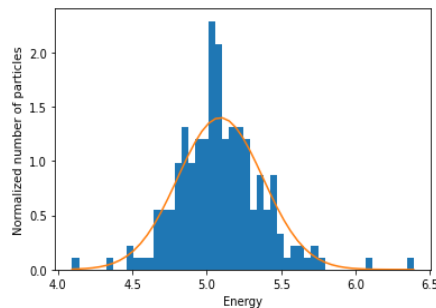
Different modules alignment on TR



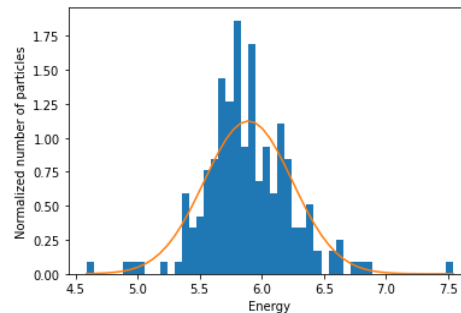
Application of ML to transition area reco

- Use DNN to classify hypothesis
- Do space transformation of glass region
- Apply convolutional DNN

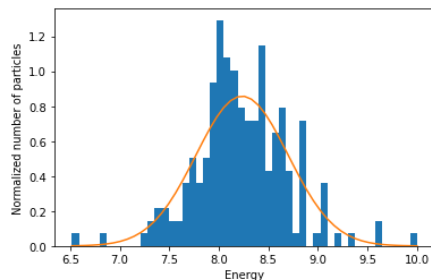
$\mu=5.09$
 $\sigma=0.29$



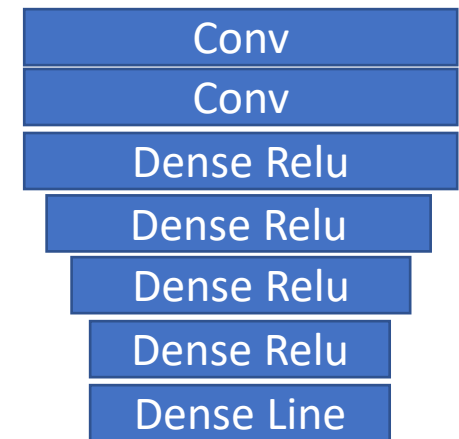
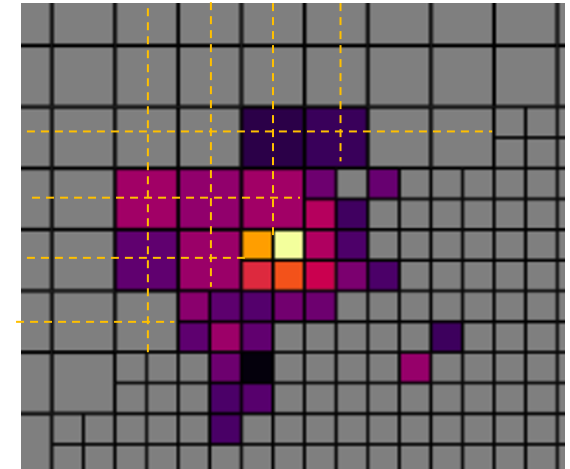
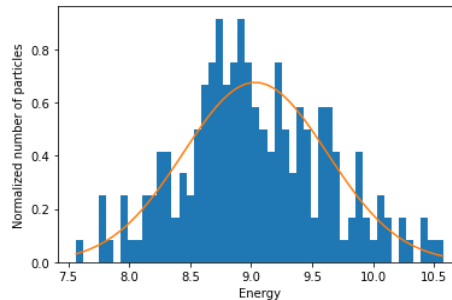
$\mu=5.89$
 $\sigma=0.35$



$\mu=8.23$
 $\sigma=0.47$



$\mu=9.03$
 $\sigma=0.59$

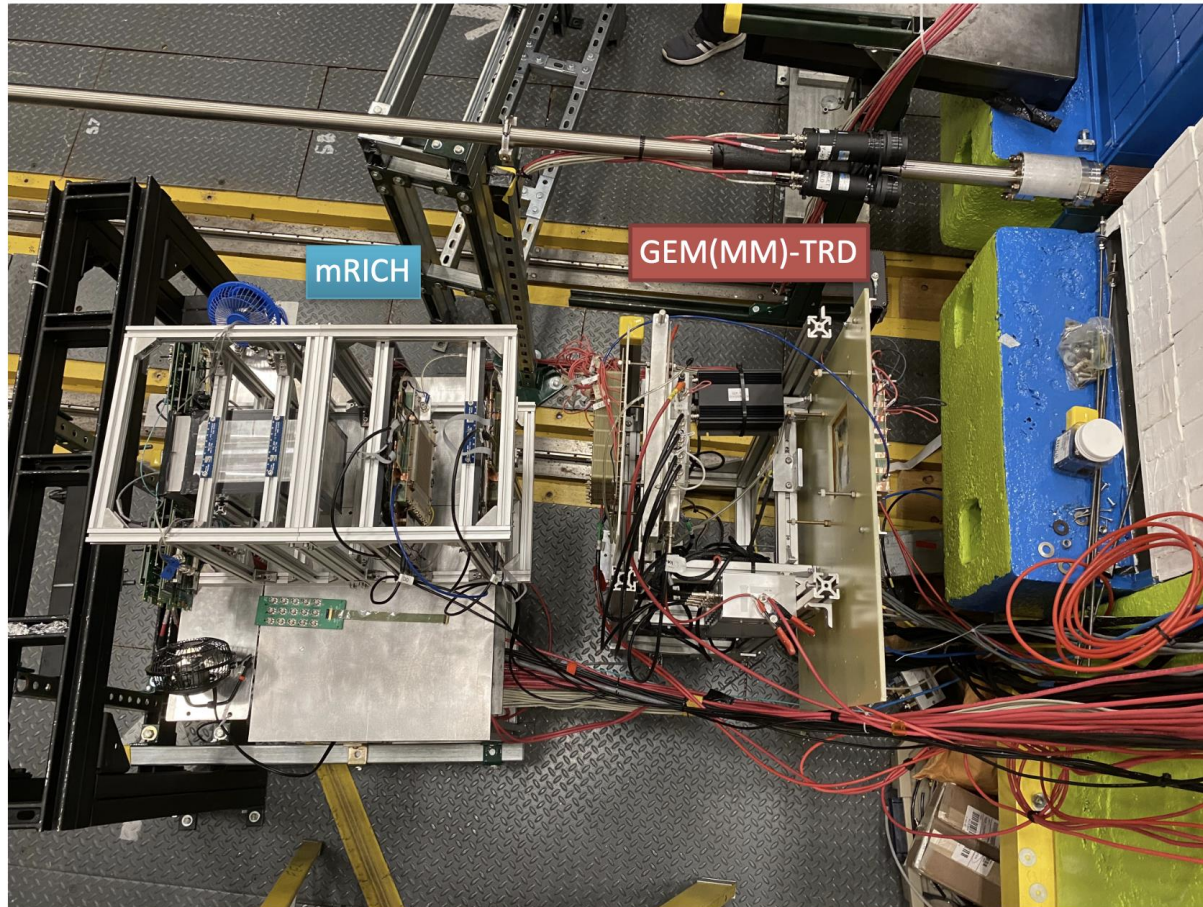


DNN Architecture

Very (very) preliminary results

ML for Calorimeter e/pi separation test stand

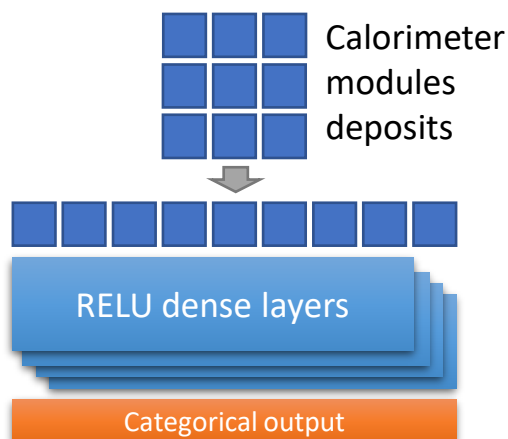
- “Event tagging and triggering on FPGA” Dr Sergey Furletov (JLab)
Thursday, 9 September (2021)



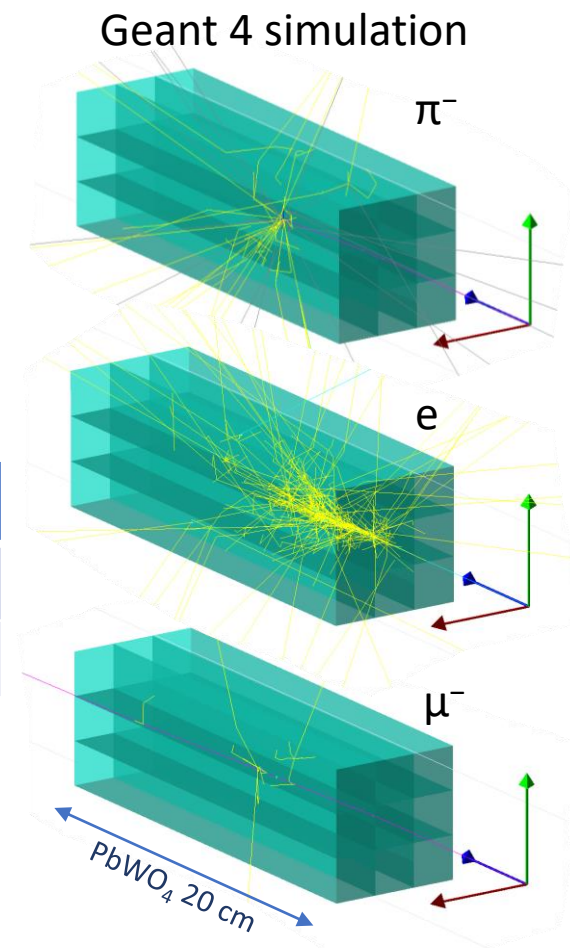
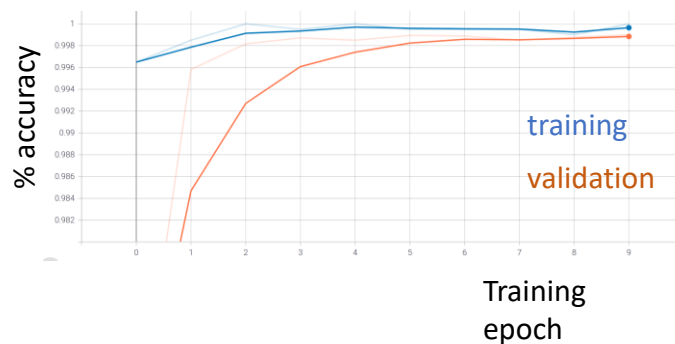
3x3 SciGlass modules are planned to be put into the real beam tests this Fall. We prepared for mRICH + GEM + Cal PID in FPGA tests

e/pi separation ML methods

- Simulated data and trained with different:
 - energy
 - angles
 - Incident cells



Classification	Last-layer activation	Loss function
single-label	softmax	categorical_crossentropy
multi-label (scores for candidates)	sigmoid	binary_crossentropy

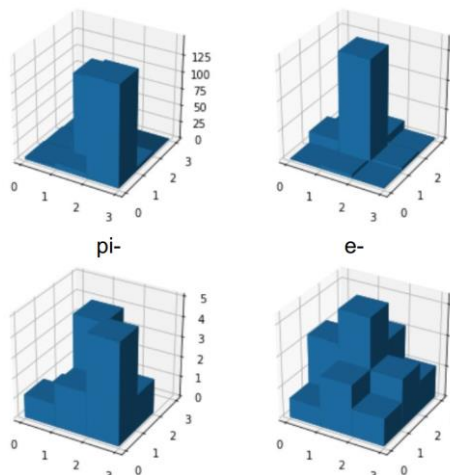


Examples of events with e and π^- showers and μ^- passing through.

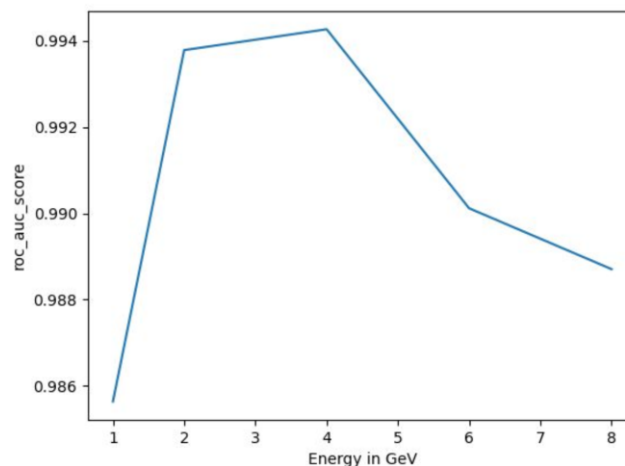
e/pi separation ML study

- A study of stability and misidentification was performed
- Application of different normalizations and transforms are tested: PCA + Log transform are the best in terms of accuracy + mismatches

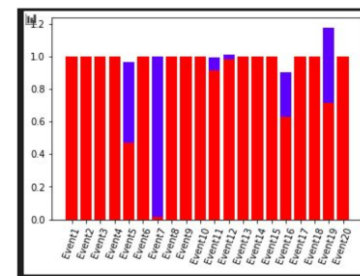
Log transform visualized



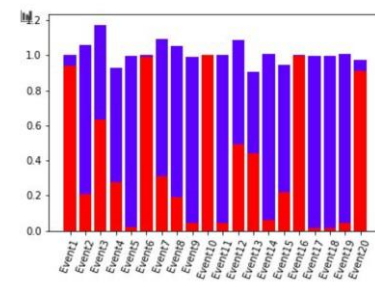
Accuracy by energy



Sample Predictions 8 GeV (Mismatched)

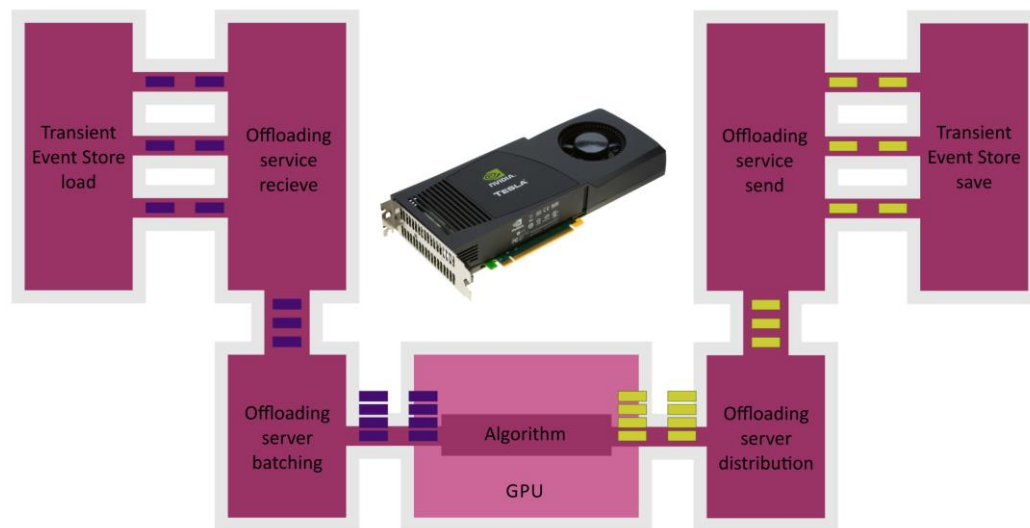
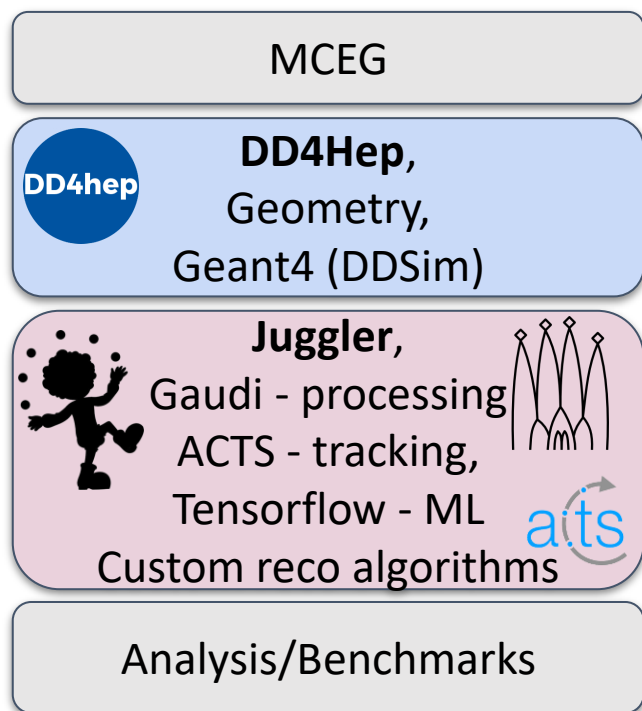


Sample Prediction 1 GeV (Mismatched)



AI software stack

- How to run ML projects in production?
- Modern software stack is being develop for EIC
- Special design for ML



Gaudi offloading service

People involved

- Tanja Horn
- Vladimir Berdnikov
- Ilya Larin
- Mariangela Bondi
- Cristiano Fanelli
- Dmitry Romanov
- Sergey Furletov
- Alexander Zaitsev
- Nathan Branson
- Hasan Mustafa
- Vinet Tripathi
- and others!

AI FOR CALORIMETRY
LET'S COLLABORATE !

Summary

- Several projects of application of various AI methods towards EIC lepton endcap calorimeter is being actively developed
- AI driven optimization is at a stage of ready pipelines and optimizer and is being in progress
- A research work on application of various ML methods for reconstruction has been performed using simulation and real data for HyCal hybrid calorimeter (similar to EIC) and EIC
- Project on PID ML in FPGA with use of calorimeter modules is preparing for real beam test (presentation by S. Furletov)
- The study of reconstruction of the transition area with ML is started and got the first very preliminary results
- Application of unsupervised learning clustering methods is set for the near future project

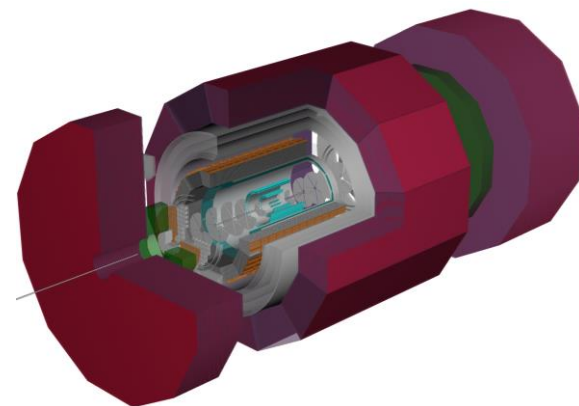
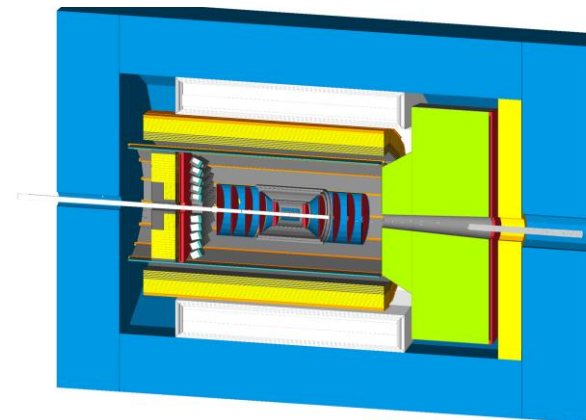
Thank you!

Questions?

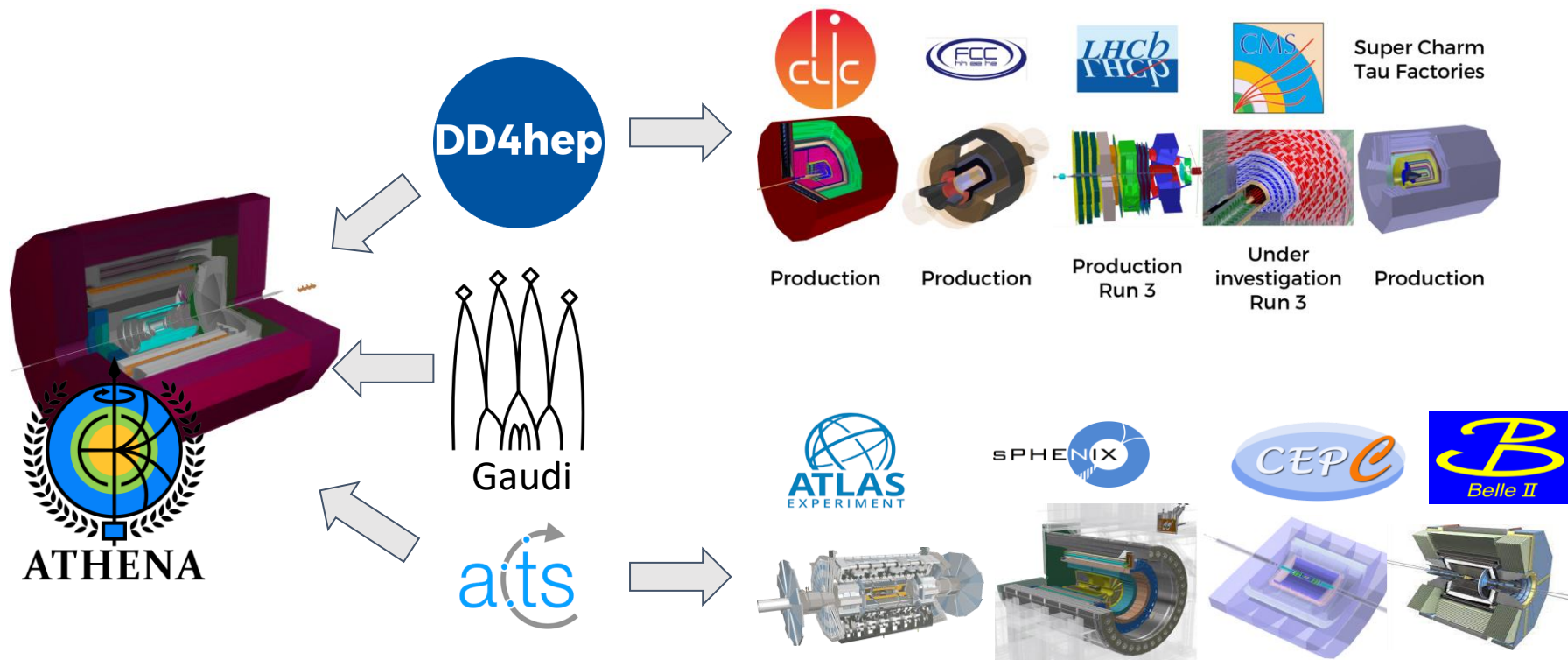
Software Philosophy:

Let's prepare for our future at the EIC

- **Build forward-looking team of software developers to ensure the long-term (decades) success of the EIC scientific program.**
- Focus on modern scientific computing practices
 - Strong emphasis on modular, orthogonal tools
 - Integrate with high performance computer, continuous integration workflows, and enable use of data-science toolkits
- Software on top of mature, well-supported, and actively developed software stack.
- Actively work with the EICUG software group to help develop and integrate new community tools.



Software component community



Summary

The physics case for the EIC was clearly laid out in the EIC White Paper and the National Academy of Science Report.

The Yellow Report took those physics requirements and turned them into detector requirements to do the science.

Photo-collaborations are presently working on collaboration proposals for the project and 2nd EIC detectors: Athena, CORE and ECCE

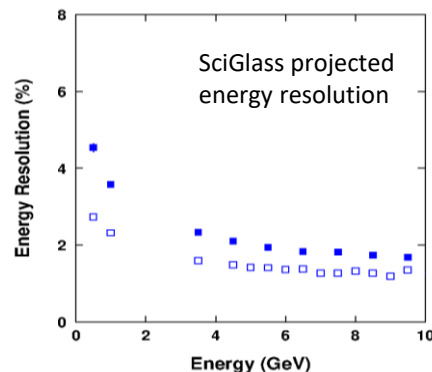
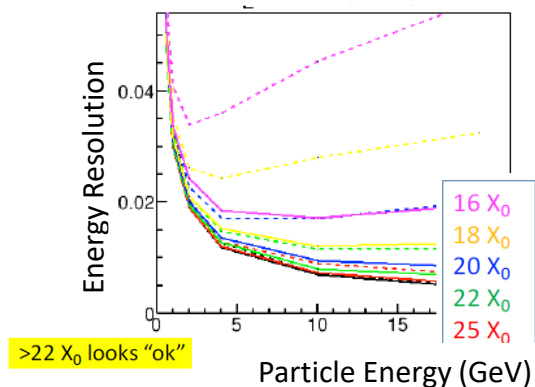
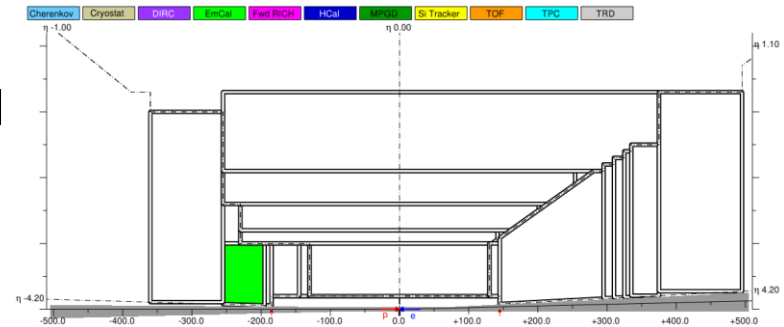
AI is already planning a major role in the optimization of these detectors and I believe this conference will make clear, these AI driven optimizations and refinements will continue as we all strive to make the best possible EIC detectors within the given space, schedule and funding parameters.

Detector development and testing key to best possible AI results!

Lepton Endcap EM Calorimeter

Electron Detection - Goal

We aim to design and construct the scattered electron detection in the Lepton Endcap covering pseudorapidity -3.5 to -1 with an electromagnetic calorimeter (**EEEMCal**).



REFERENCE

PbWO₄ crystals (inner)

- compact, radiation hard, luminescence yield to achieve high energy resolution, including the lowest photon energies
- Sensor: SiPMs (TBC)

SciGlass (outer)

- EIC eRD1
- radiation hard, luminescence yield similar or better than crystals depending on longitudinal length
- Sensor: SiPMs (TBC)

